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Locating and Repairing Leaks in Landfill/Impoundment Flexible Membrane Liners

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16. ABSTRACT

In the United States, the large quantities of solid and hazardous wastes generated each year are commonly disposed of in landfills and surface impoundments. Because the liquids (leachates) in surface impoundments and landfills are frequently toxic, nearby surface water, groundwater, and soil must be protected.

Geomembrane liners (flexible membrane liners, FML's) are often used to form an impermeable barrier to prevent migration of contaminant liquids to nearby soil and water. The factory-fabricated sheets of polymeric materials are seamed together at a field site to form a continuous barrier between the landfill/impoundment (L/I) waste and the surrounding environment. As a pollution barrier this FML must be sound and without defect. While the FML is being installed or while the L/I is being operated, however, the FML can be punctured or seams can separate.

An effective method was needed not only to locate leaks in FML's before waste materials are introduced but to isolate leaks for subsequent repair in operating L/I's. The United States Environmental Protection Agency (EPA), recognizing the enormity and the implications of this problem, undertook a research program to determine where the leaks were, how to get to the leak, and how to repair the leak.

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INTRODUCTION

In the United States, the large quantities of solid and hazardous wastes generated each year are commonly disposed of in landfills and surface impoundments. Because the liquids (leachates) in surface impoundments and landfills are frequently toxic, nearby surface water, groundwater, and soil must be protected.

Geomembrane liners (flexible membrane liners, FML's) are often used to form an impermeable barrier to prevent migration of contaminant liquids to nearby soil and water. The factory-fabricated sheets of polymeric materials are seamed together at a field site to form a continuous barrier between the landfill/impoundment (L/I) waste and the surrounding environment. As a pollution barrier this FML must be sound and without defect. While the FML is being installed or while the L/I is being operated, however, the FML can be punctured or seams can separate.

An effective method was needed not only to locate leaks in FML's before waste materials are introduced but to isolate leaks for subsequent repair in operating L/I's. The United States Environmental Protection Agency (EPA), recognizing the enormity and the implications of this problem, undertook a research program to determine where the leaks were, how to get to the leak, and how to repair the leak.

LOCATING THE LEAKS

The Agency established three major objectives to identify where, within a landfill or surface impoundment, the leak was actually occurring. The objectives were (1) to develop a nondestructive technique capable of locating the leak within a 1-square-foot area, and (2) develop the ability to detect leaks at existing facilities and in planned facilities. Two research projects were selected to pursue these objectives.

The first project[1] surveyed 28 geophysical techniques; 20 of these were identified as having potential as leak detection techniques. As expected, no single technique proved applicable to all situations. From this study, two techniques were thought to have sufficient potential for additional study: the time-domain reflectometry (TDR) and acoustic emission monitoring. The subject of the second project was an electrical resistivity technique believed to hold high promise to meet the stated objectives.

Acoustic Emission Monitoring

Acoustic emission monitoring techniques have been used for over 50 years to evaluate stresses in rocks and metals. Its application has more recently been extended to monitor fluid flow through soils. Normally, fluid passing through soils is not turbulent, but it can be if there is a sufficient head or potential, as might be expected in a surface impoundment.

Laboratory experiments were conducted[2] to determine characteristics of the sounds that are produced when liquids flow through soils at different rates, the spectral characteristics of the equipment, and the attenuation of these sounds over the frequency spectrum observed for the laboratory experiments.

The acoustic emission monitoring techniques showed that acoustic sounds, at frequencies up to 500 Hz, are emitted at turbulent flow rates of 0.3 to 1 cm/sec through sand and pea gravel. The amplitude of the acoustic sounds is 100 times greater than that of the ambient background noise level that may exist at a surface impoundment. It was also determined that at a frequency of 450 Hz, the acoustic sounds have an attenuation of 0.5 dB/m at a depth of 1 meter in an impoundment. These data suggested the potential of locating a leak with a flow rate of 1 cm/sec at a range of 3 meters from the leak.

Field tests were performed in a 1-acre impoundment that had known man-made leaks. However, the field results were less encouraging. The sound attenuation within the impoundment was found to be greater than that reported in the literature, and there were insufficient background-to-water-flowing-noise ratios to efficiently determine leak location. Although recommendations for improvement were made, it was decided not to develop this technique further.

Time-Domain Reflectometry

TDR is less well known and a more recent technique than is acoustic emission. TDR combines a wide-frequency band with a short-pulse-length measurement technique that is sensitive to the high frequency (10^6 to 10^9 Hz) electrical properties of the materials in and around the conductors of a parallel transmission line.

This potential technique requires that parallel wires be placed under the liner. The technique then detects moisture between the wires, unlike other systems where the wires have to corrode. TDR laboratory experiments showed that a leak with dimensions equal to or greater than half the spacing between the parallel transmission line conductors can be detected. Only 2-m conductor spacing was tested, but larger spacings were thought feasible.

Field testing of the TDR techniques was also made on a 1-acre impoundment (the same impoundment as the acoustical emission technique). For the type of equipment used, the length of the transmission lines, the spacing of the lines, and the soil used, the system worked as predicted.

Although recommendations were made on how to improve the electrical instrumentation and build a total system, it was decided not to pursue additional development of this technique, because (1) this system required the installation of transmission lines before placement of the FML, (2) the long-term durability of the system was questionable, and (3) excellent results were being obtained using the electrical leak location method.

Electrical Leak Location

A third technique,[3,4] undertaken by separate contract, was the electrical leak location (ELL) method. This method adapts electrical geophysical analysis techniques to leak location and assessment of damaged FML's. The ELL method makes use of the high electrical resistivity of FML material. In a lined L/I, the current flows through the waste material, the liner, and the leaks to return to the current electrode in the soil layer (Figure 1). When no leaks are present, a voltage impressed across the liner produces a very low current flow. The low current density produces a relatively uniform voltage potential distribution in the material above the liner. A leak in the FML provides a conductive path for current flow, which produces an increase in the current density at the leak point. Because the localized current density causes an electrical anomaly in the measured potential in the vicinity of the leak, leaks can be located by measuring the potential distribution patterns in the material covering the liner. The ELL method can be used in liquid impoundments or as a pre-service inspection of solid waste landfills. To locate leaks in the final L/I cover, a modified sensor has to be used.

Computer Simulation Model--

Because evaluating electrical survey techniques under a wide range of parameters (such as liquid depth, liquid conductivity, liner resistance, and earth resistivity) is impractical, formulating a computer simulation model to obtain numerical computations that correspond to field installations is a practical alternative. Obtaining these numerical computations before making measurements at in-service L/I's also increases confidence in the measured results.

A theoretical model was developed to include the electrical and dimensional parameters in the three layers comprising a lined L/I as well as the number of leaks and locations of the current source and potential measurement electrodes. To simplify the model, the L/I, the liner, and the soil under the liner were represented as infinite horizontal layers and the liner thickness and the leak size were assumed to be much smaller than the other liner dimensions.

A model was also developed to simulate a landfill cover system. In a landfill cover system, the current flows through the cover material, the liner, and the leaks to return to the current electrode in the soil layer. Because cover systems are generally a few feet deep and many have surface areas of several acres, lateral current flowing across the perimeter of the cover is much smaller than current flowing through the lined bottom and the leaks. Therefore, the total current distribution that returns to the sink current electrode may be assumed to be equal to the currents flowing across the lined bottom of the cover system plus the currents flowing through the leaks.

To demonstrate the validity of the ELL method to predict leak signatures, synthetic signatures were compared with pole-dipole measurements taken at a 1-acre, lined, impoundment test site. The tests were made before the site's use to demonstrate the electrical techniques and to develop field procedures for conducting such tests.

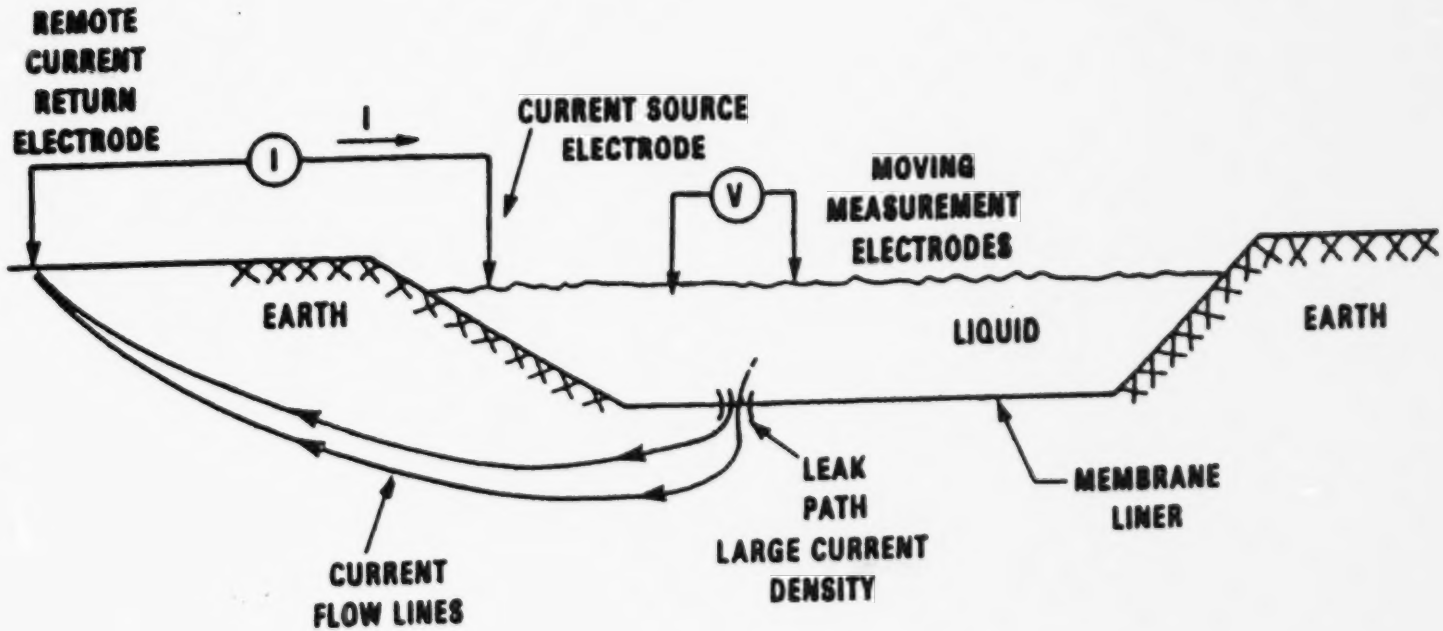

Figure 1. The electrical leak location method locates leaks by detecting the electrical potential anomaly associated with electrical current flowing through a leak.

Experimental results indicated that:

- the pole-dipole electrode array is more sensitive to small leaks than is the pole-pole array;
- A DC power supply is preferable to an AC supply since the current flow through the capacitive reactance of the liner is eliminated;
- the pole-dipole anomaly of a leak in an FML has a characteristic bipolar potential gradient and that detecting such anomalies depends on impoundment depth, leak size, waste material resistivity, underlying soil resistivity, measurement dipole depth and proximity to the leak, source excitation current, etc.;
- either horizontal or vertical dipole detectors can be used to acquire field data, but the horizontal dipole response is stronger because of the proximity of the two electrodes to the plane of the liner;
- multiple leaks located far apart are more easily detected than are multiple leaks located close together.

With the aid of the present computer model, the subsurface depth as well as the dipole spacing (for resolving the presence and location of multiple leaks) can be specified.

The computed parametric curves can be used to plan optimum electrical surveys for a range of field conditions, depending on FML depth and resistivity of the waste material. The computed leak responses show the importance of taking measurement near the bottom of the L/I to enhance the anomaly.

The excellent agreement between the calculated and the experimental model data establishes the ability of the model to predict leak signatures (Figure 2).

Double-Liner Model Tests--

To meet EPA minimum standards, hazardous waste L/I's must be double lined with FML. The applicability of the ELL method to detect and locate leaks in the upper liner was tested.

With the current return electrode placed in electrical contact with the liquid-saturated drainage layer between the two liners, the double-liner model studies tested:

- drainage layers composed of different combinations of geotextile, geonet, and soil;
- various sizes of leaks;
- a protective soil cover;
- various electrode materials;
- various electrode shapes.

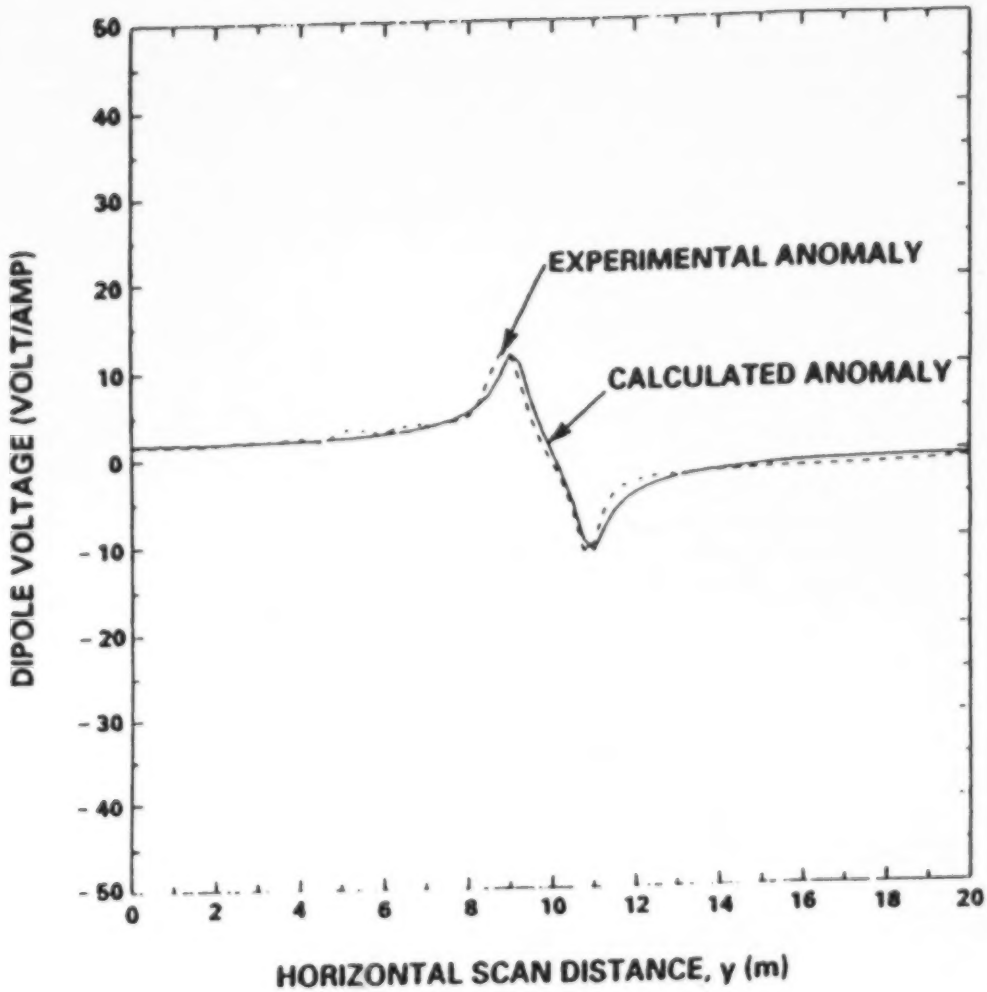

Figure 2. Comparison of experimental leak response and theoretical response predicted for the same field conditions.

To optimally apply the ELL method, there should be an electrically conductive layer between the liners that is not grounded to the earth except through the leak and the design of the drainage layer should provide access to place a current return electrode.

The double-lined model experiments successfully demonstrated the usefulness of the ELL method to detect and locate small leaks in L/I's with a wide variety of drainage layer types, leak sizes, and geometries. The method was less sensitive for locating leaks under a protective soil cover immersed in water. Simple electrical continuity tests determined the presence of, but not the location of, leaks in the bottom liner of a double-lined L/I.

The electrode material and geometry affected the sensitivity and probability of locating leaks. Polarization noise was greatly decreased with the use of carbon electrodes; this, in turn, allowed higher gain to be used in the measurement amplifier and, hence, permitted higher sensitivity. Linear electrodes scanning perpendicular to the scan direction were less likely to miss a leak than were localized electrodes.

Locating Leaks in Cover Systems--

FMLs are widely used as part of the final cover system for landfills to prevent rainwater from percolating through the waste and leaching chemicals into groundwater or surface water. A typical cover system consists of a low permeability bottom layer (e.g., a plastic liner over a layer of clay placed over the waste); a middle drainage layer of sand and gravel; and a top layer of soil and vegetation. Because such cover systems are intended for long-term storage of hazardous waste, there is the need to ensure that the cover system performs as intended. The ELL method and several alternatives were investigated to determine their applicability for this purpose.

The accuracy of surface earth potential measurements to locate leaks depends on several factors. The presence of instrument noise, poor electrical contact between the ground and the electrodes (measurement noise), localized inhomogeneities of the surface resistivity (geological noise), electrode polarization noise, and the presence of interfering signals such as electrical power line interference (electrical noise) all serve to decrease accuracy. A half-cell electrode, which reduces polarization noise significantly, was used in the tests.

The ELL method, adapted to make surface soil potential measurements with the use of half-cell electrodes, was well suited for locating leaks in L/I FML's with protective soil covers. Small leaks were located in an FML covered with soil without the need for an overlaying conductive layer of liquid. To reduce electrode contact noise, the electrodes were inserted into the soil to penetrate the dry surface soil. It was determined that surveys can be performed after the protective soil is put in place so that leaks caused by placing the soil can be located.

Liner Resistivity Tests--

The success of the ELL method is influenced by the electrical resistivity of the liner. The liner material must have a substantially greater resistivity than does the soil beneath the liner and the liquid above the liner. Does the

electrical resistance of FML's change after exposure to waste liquids and thereby reduce the usefulness of the survey technique for in-service L/I's?

A series of tests measured electrical resistance changes in selected liner materials over a period of time. Several FML materials were tested: polyvinyl chloride (PVC); high-density polyethylene (HDPE); 0.91-mm chlorosulfonated polyethylene (CSPE); 1.14-mm chlorosulfonated polyethylene (CSPE); and chlorinated polyethylene (CPER). In the tests, four liquids used: aklaline (sodium hydroxide solution, pH 10); acidic (sulfuric acid solution, pH 1); brine (sodium chloride solution 10% by weight NaCl dissolved in deionized water); and deionized water.

The test results indicated the measured resistance values of the FML's were at least two orders of magnitude greater than the resistance needed to use the ELL method. The relatively minor changes in electrical resistivity did not affect use of the method; the trend was for the materials to have a slightly enhanced applicability to the technique.

Throughout the United States, liner materials are exposed to a variety of wastes far exceeding those used in the tests. After long-term exposure to given waste liquids, the specific liner material should be tested to understand how different wastes alter the chemical and electrical properties of liner materials.

Field Demonstration Surveys--

Although previous field tests at a demonstration site had demonstrated the usefulness of the ELL method under full-scale conditions, additional investigations were needed to demonstrate the ELL method at a pre-service facility and at an in-service facility. The EPA Land Treatment Research Demonstration Facility near Ada, Oklahoma, was selected as one site. It includes two 0.6-hectare (1.5 acre) HDPE-lined liquid impoundments. The second site was a full-scale, double-lined impoundment, constructed but not yet placed in service, near San Antonio, Texas.

The equipment measured potential gradients, logged the data, and plotted the results. The system detected the presence of 0.8-mm (0.031 in.) leaks 1.5 m (5 feet) away from the leak. These leaks can be located with an accuracy of less than 15 cm (6 in.) when electrodes pass 15 cm (6 in.) above the leaks.

The field demonstration of the ELL method at a facility near San Antonio was also successful. Because the impoundment had been tested using the vacuum box method and because subsequent follow-up tests revealed no additional leaks, the one leak found was most likely the only leak. No false indications were obtained.

The ELL method proved successful in acquiring high-quality data, but the survey was time consuming. A faster data acquisition rate is needed to make the ELL method more cost effective.

REACHING THE LEAK AREA

After the leak is located in a landfill, the landfill must be excavated to reach the leak area for repair and sealing. Because each landfill is different -- there is no typical landfill -- many factors must be considered before determining how to excavate.

- How dense is the waste? Estimates can vary between 800 and 1,500 lb/yd^3. Density influences both the rate at which the fill settles and the bearing capacity of the completed fill.

- How well has the fill settled? Decomposition, accelerated by water, is the prime factor influencing settlement. What kind of wastes? How well composted?

- What is the landfill's bearing capacity? How well will the landfill support heavy equipment?

- What is the landfill's decomposition rate? Decomposition varies with the kind of waste. Under anaerobic conditions, decomposition of organic material forms highly corrosive acids and also explosive and toxic gases.

All these factors differ from landfill to landfill, and all must be known to determine if the area can be excavated[5] and how to go about doing it. Several techniques have been identified[5] that would allow access to the leak area. It should be pointed out that these have not been field tested at landfills, but the technologies have been successfully demonstrated at other engineering sites.

REPAIRING THE LEAK

The next phase of this program was to develop techniques to effect the repair[6]. But can temporary, and possibly permanent, in situ repairs be made on FML's? Can repairs be made during installation? After in-service use?

A number of different polymers have been used as FML's. They may be either unreinforced or fabric reinforced and either cross-linked or theromoplastic.

Most of the polymeric FML's that have been or are being manufactured are of the thermoplastic type and, generally, are not cross-linked. Although cross-linked liners are more chemically resistant, thermoplastic liners are easier to seam and to repair in the field.

The methods used to seam and test the seam quality of a particular FML are the same ones used to repair that FML. FML's can be seamed with the use of:

- thermal methods (heat gun, extrusion welding, hot-wedge method, heat sealing, dielectric seaming);

- solvent methods (solvent welding, bodied solvents);

- adhesives (vulcanizing adhesives, contact adhesives); and

- tape adhesives (pressure-sensitive adhesive tapes).

The quality of seams can be tested by:

- immersing the FML seam in the waste medium to determine chemical compatibility and then measuring the effect on adhesion;

- nondestructive testing where seams are tested without being disturbed (e.g., visually; or testing coupons prepared with the same equipment and procedures used during actual seaming operations); and

- destructive testing in which samples of the seam are cut from the actual liner.

The need to repair an FML may occur at any of three major phases in the service life of the FML:

- at the time of and immediately after installation (e.g., repair damage that took place during installation or repair defective seams that show up during inspection and quality assurance testing);
- shortly after installation when the FML may have been partially covered with soil or may have undergone performance-type inspection; or
- after the facility has been placed in service and the FML has been in contact with wastes and covered with soil.

At the time of installation, the FML is generally only a few weeks old and has aged little. At this time repairs can be made employing the same preparations and methods that are used to seam the panels.

Shortly after installation, the FML is somewhat older, and although not exposed to weathering to the degree that aging has become an important factor, the sheeting may have become dirty. A successful repair now depends on having the FML clean and free from contamination.

After the L/I has been placed in use, the in-service life of the FML can range from a few weeks until the site is closed, and beyond. Even when the changes in FML composition are slight and do not affect overall performance of the liner, they can reduce repairability. To achieve a good bond, the composition of an exposed liner must match, on a molecular scale, that of the patching material and the surface must be clean and free of moisture and other contamination--conditions difficult, if not impossible, to meet. FML's exposed to waste liquids may have absorbed even small amounts of water and organic constituents from the waste liquids or have lost components, (e.g., plasticizers and anti-degradants) to the waste liquids.

Repairs to FML's at any aging stage may also be made with liquids that will harden on curing, such as epoxies if (1) good mechanical bond can be made between the liner and the plug, (2) the plugging material is deliverable to the repair location, and (3) the plugging material is compatible with the FML and the waste liquid during the curing process and the subsequent exposure.

Both of these techniques, patching with the same material[7] and temporary seals[8] have been attempted with limited success. The limited success stresses the need for additional research for repair of in service liners. Although mechanical seals were not investigated, they may have some application.

SUMMARY

Research has developed techniques to pinpoint the location of leaks in FML's within a very small area. Construction techniques are available to physically get to the leak. However, the ability to repair that leak on more than a temporary basis is questionable. The implications of this situation are obvious: permanent repair techniques for damaged membranes must be developed,

additional controls need to be employed at waste management facilities, or alternative methods of disposal must be found. The Agency has taken the leadership role of requiring additional controls, i.e., double-liner systems, while continuing to reevaluate other alternatives.

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